1. Size – The domain of Physics

How big are things; stuff we see every day, stars and planets, the universe, molecules, atoms or what atoms are made of? We live on the Earth, roughly a sphere of approximate diameter 12,800 km. This means it is 40,100 km in circumference. If we were travelling continuously in an airliner travelling at 900 km an hour we could go all the way round in about 45 hours.

If we were in a space ship going to the moon at the same speed it would take about 18 days, and to the sun would take 19 years! To the nearest star it would take over 5 million years!!

It is not sensible to think of the whole range of sizes at once. We tend to "package" sizes into roughly defined chunks. The easiest to manage is "**macroscopic**". These are sizes that we use every day. From a few hundredths of a millimetre needed in accurate engineering to distances we may travel to around the world on holiday or for business.

Let's start be going down in size.

Going Down

If we go down in size to the "**microscopic**" we think of those things that we might see with an optical microscope. Small biological structures like cells 10-100 micrometres. Here it is necessary to think of smaller fractions of a metre than just a millimetre. A *micrometre* is one millionth of a meter, or one thousandth of a millimetre. Powerful optical microscopes can detect objects down to about 0.2 micrometres. This will enable study of cells and bacteria, but not viruses. Viruses range in size from about 5 to 300 nanometres. This is another new unit. A *nanometre* is one thousandth of a micrometre. Electron microscopes can detect down to 0.04 nanometres which allows details at the atomic scale – but not within an atom itself.

So if we consider optical and electron microscopes we can think of a range down to about 0.04 nanometres. To get an idea of what this means we can work out how many objects of size 0.04 nanometres would fit into I millimetre on a ruler. The answer is 25,000,000 i.e. 25 million.

This is not the end of the story. To look at the structure within an atom we need to go down in size to a *femtometre*. This is one millionth of a nanometre. This unit is needed to talk about the sizes of the individual particles that make up an atom. This is in the range of the "**femtoscopic**". A proton – one of the constituents of all atoms is just under one femtometre. So if we now ask how many protons side by side (which would be absolutely impossible achieve) in a 1 millimetre space on a ruler the answer would be: 1,000,000,000,000 i.e. one trillion.

Quarks, which make up protons have been proven to be less than one thousandth of the size of a proton. But let's not go there.

Name of size range	Rough range
macroscopic	Thousands of km down to a fraction of a millimetre
microscopic	Fraction of a millimetre down to nanometre
femtoscopic	Fraction of a nanometere and less

A millimetre is one thousandth of a meter
A micrometre is one thousandth of a millimetre
A nanometre is one thousandth of a micrometre
A femtometre is one *millionth* of a nanometre

Going up

If we now go up in size it is best to start with the macroscopic. Otherwise there are just too many zeros when the numbers are written out.

Going up in size it soon becomes senseless to stick with km as our unit of distance. We change to *light-years*, or *light-minutes* or *light-seconds*. These are the distances light travels in one year, one minute, and one second respectively. This helps because light travels very fast and so these units can describe very large distances.

Light travels at nearly 300,000 km per second. To compare this with our airliner we need to change this to km per hour. An hour has 3600 seconds so with a calculator this gives light the speed of 1,080,000,000 km per hour. This is 1,200,000 times faster than our airliner. If you do the sums it works out that light gets to the Moon from Earth in 1.3 seconds, rather than the 18 days for the airliner. We say the Moon is 1.3 light-seconds from the Earth. For the Sun the sums work out at 8.3 light-minutes compared to the 19 years. And to the nearest star light takes 4.2 years and so is 4.2 light years away. If we try to use our 1 millimetre on a ruler as a base we are in deep trouble. The nearest star is 40,100,000,000,000,000 millimetres away.

This makes it clear that travelling to the nearest star is not a remote possibility. To get near the speed of light would mean getting to a speed 1,000,000 faster than an airliner. In fact physics shows that it gets more and more difficult to go faster for any object getting near to the speed of light. Getting to the speed of light is theoretically impossible.

For the solar system, the Sun and the planets, we could use light-minutes as a basis. I light-minute is about 18,000,000 km. Then the Earth is about 8 light-minutes from the sun, Jupiter is about 43 light-minutes and Pluto is averagely about 360 light-minutes or 6 light-hours.

To understand distance to stars and other objects out in space it is necessary to have a picture of what is out there. When you look up into the night sky everything you see (almost) is in our own *galaxy* called the “Milky Way”. To get a picture imagine two dinner plates put together with one upside down. The shape of own galaxy is the shape of the space between the plates. All stars we see in the sky are dotted around in this shape. Our sun is just one of these stars.

Apart from stars there are regions of gas that glow. These are *nebulae* and can be the birth place of new stars. There are also *globular clusters* of many thousand stars relatively close together. But all these objects are in our own Milky Way galaxy. (why it is called this would be a bit of a digression).

Things in our own Milky Way

Nebulae	Globular clusters	Nebulae from exploding stars
		
Luminous regions of gas with the bright area birthing new stars.	A cluster of some half a million stars.	The result of an exploding star leaving a central white dwarf.

The diameter of our galaxy is about 100,000 light-years. Our sun is about two thirds of the way out from the centre. It is a very average star among the 100+ billion stars that comprise the Milky Way. It is a belittling thought. But it gets worse.

Galaxies

Our galaxy is just one of upwards of 200 billion galaxies. The nearest one is the Andromeda galaxy and can be just seen with the naked eye in very clear dark conditions. If our eyes were very sensitive it would occupy a decent portion of the sky looking in length about 5 times the diameter of the moon. It is 2.5 million light years away and contains roughly a trillion stars. The farthest galaxy that we know at the moment is 34 billion light-years away. With evidence coming in from the JW telescope this will soon be out of date.

A galaxy seen edge on	A galaxy seen face on
	
This galaxy shows what our Milky Way would look like seen edge.	This galaxy shows what our Milky Way would look like seen face on.

This summarises the range of sizes for astronomical objects

System	What it contains	Size
Solar System	All the planets, including Earth, asteroid and comets	12 light-hours diameter
A galaxy	Billions of stars, nebulae, globular and other star clusters	Varies but around 100,000 light-years
The universe	A current estimate is 200 billion galaxies	34 billion light-years

All sizes at Once

The big bang theory of the Universe – generally accepted – is that everything in the universe started off at a tiny point, smaller than the sizes we talked about earlier. The detailed interaction of particles and energy at these tiny distances, probed by the Large Hadron Collider, are used by theoretical physicists to try to explain the universe as we now experience it. From a big bang with the tiniest of dimensions 13.7 billion years ago to the unimaginably large distance we find in our current knowledge of the universe.

There is a shorthand for writing the very large and very small numbers that we have been using explained I the next section.

Writing very big and very small numbers

It is a nuisance, and not always communicative, to write numbers with lots of zeros before or after a decimal point when writing very large and very small numbers. To see what these mean you need to count up the number of zeros to make sense of it. Fortunately some simple Maths solves this problem.

Think of 100. This is 1 followed by two zeros. It represents 1 x 10 x 10. Each time we multiply by 10 it adds a zero. 2000 is 2 x 10 x 10 x 10. There is a shorthand for writing the same number multiplied by itself a number of times. We write the number of times as a little number written high and to the right.

So 100 = 10 x 10 is written as 10^2.
1000 = 10 x 10 x 10 is written as 10^3

A very big number like a billion = 1,000,000,000 has 9 zeros and so is 10 multiplied by itself 9 times so one billion is written 10^9

A similar idea works for small numbers. 0.002 is 2 divided by 1000. It is 2 thousandths. So it is 2 divided by 10 three times over. To show we are dividing we put a minus sign together with the number of times we are dividing. This means we can write .002 as 2 x 10^{-3}

Using this notation here are the distance units we have been using expressed in metres.

Units less than 1 metre

Unit name	Power of 10 notation
Femtometre (fm)	10^{-15}
Picometre (pm)	10^{-12}
Nanometre (nm)	10^{-9}

Unit 1 metre and more

Micrometre (µm)	10^{-6}
Millimetre (mm)	10^{-3}
Metre (m)	1
Kilometre (km)	10^{3}
Megametre (Mm)	10^{6}
Gigametre (Gm)	10^{9}
Terametre (Tm)	10^{12}
Petametre (Pm)	10^{15}
Exametre (Em)	10^{18}

The proton is about 1 femtometre – A simple atom is about 10 picometres.
A cell membrane may be 10 nanometres and a typical bacterium is between 1 and 4 micrometres
You can picture for yourself sizes between 1 millimetre and 1000 kilometres.

The diameter of the Earth is approximately 6.4 megametres, whilst the diameter of the Sun is 1.4 gigametres. Saturn orbits 1.4 terametres from the Sun.

Only with these large units do we now get to light-years. I light-year is 9.5 petametres. After this it is more convenient to change to light-years rather that use the Exametre.

The prefixes M, G, T, P, E can apply to any unit so a Gly (giga light year) is 10^{9} light-years!

Summary

From the smallest things that Physics deals with to the largest is about 10^{40} . This is 1 followed by 40 zeros. The mind is entitled to boggle!